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He/She further declares that all statements made herein of his/her own knowledge are true and that all statements made on information and beli ef are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 27th day of May, 2004

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[Name of Document] Specification

[Title of the Invention] OPTICAL COMPONENT, OPTICAL DEVICE AND OPTICAL COMMUNICATIONS SYSTEM

[Claims]

[Claim 1] An optical component comprising: a transmissive type diffraction grating element having a diffraction grating formed in one face of a flat plate, or in the inside of the flat plate in parallel with said face; and a prism which receives light diffracted by said diffraction grating element at a first surface and output the same from a second surface;

wherein said prism is made from a material having a refractive index n_1, and said diffraction grating element and said prism are disposed in a medium having a refractive index n_0; and

when light of wavelength λ is incident on said diffraction grating element at an incident angle of θ_0, then taking the incident angle of the light incident on said first surface of said prism, from said diffraction grating element, to be θ_2, taking the emission angle of the light emitted from said second surface of said prism to be θ_5, taking the temperature coefficient of the diffraction angle in said diffraction grating element to be F_g, taking the temperature coefficient of the emission angle θ_5 of the light emitted from said second surface of said prism, assuming that the incident angle θ_2 of the light incident on said first surface of said prism is uniform regardless of the temperature, to be F_p, and taking the

magnification rate of the angular dispersion caused by said prism to be M_p, there exist a wavelength λ and an incident angle θ_0 which satisfy the relationship "$n_1 > n_0$ and $|\theta_5| > |\theta_2|$" or "$n_1 < n_0$ and $|\theta_5| < |\theta_2|$", whilst also satisfying the relationship "$-2M_pF_g < F_p < 0$" or "$-2M_pF_g > F_p > 0$" .

[Claim 2] An optical component according to claim 1, wherein the relationship "$F_p = -M_pF_g$" is satisfied at any temperature within the temperature range of −20°C to +80°C.

[Claim 3] An optical component according to claim 1, wherein, taking the temperature coefficient of the emission angle θ_5 of the light emitted from said second surface of said prism to be F_t, and taking the angular dispersion of said emission angle θ_5 to be D_t, the absolute value of the ratio (F_t/D_t) is less than 0.4 pm/°C at any temperature within the temperature range of −20°C to +80°C.

[Claim 4] An optical component according to claim 3, wherein the absolute value of the ratio (F_t/D_t) is less than 0.2 pm/°C, at any temperature contained in the temperature range of −20°C to +80°C.

[Claim 5] An optical component according to claim 1, wherein, taking the angular dispersion of said diffraction grating element to be D_g, taking the temperature coefficient of said angular dispersion D_g to be G_g, and taking the temperature coefficient of the magnification rate M_p of the angular dispersion caused by the prism to be H_t, then the relationship "$-2M_pG_g < H_tD_g < 0$" or "$-2M_pG_g > H_tD_g > 0$" is satisfied.

[Claim 6] An optical component according to claim 5, wherein the relationship "$-M_pG_g = H_tD_g$" is satisfied at any temperature within the temperature range of −20°C to +80°C.

[Claim 7] An optical component according to claim 1, wherein, taking the grating period of said diffraction grating to be Λ, then the temperature coefficient of the product ($n_0\Lambda$) has a negative value, and the temperature coefficient of the ratio (n_1/n_0) has a negative value.

[Claim 8] An optical component according to claim 1, wherein said prism is made from a semiconductor.

[Claim 9] An optical component according to claim 8, wherein said semiconductor is silicon.

[Claim 10] An optical device comprising the optical component according to claim 1, wherein light is multiplexed or demultiplexed by the optical component.

[Claim 11] An optical device according to claim 10, wherein said optical component is hermetically sealed inside an enclosure.

[Claim 12] An optical communications system, comprising the optical device according to claim 10, wherein signal light is transmitted, and the signal light is multiplexed or demultiplexed by the optical device.

[Detailed Description of the Invention]

[0001]

[Technical Field of Utilization]

The present invention relates to an optical component

including a diffraction grating element, an optical device including the optical component, and an optical communications system including the optical device.

[0002]

[Prior Art]

A diffraction grating element comprises a transparent flat plate, and a diffraction grating formed on one surface of the flat plate or formed within the flat plate in parallel with the one surface (see, for example, Non-Patent Reference 1). In this diffraction grating element, light incident on the diffraction grating is diffracted by the diffraction grating. The diffraction angle of the light in this case differs according to the wavelength of the light. In other words, when light of wavelength λ is input to a diffraction grating of diffraction period Λ at an incident angle of θ_0, then the emission angle θ_1 of the mth-order diffraction light emitted from the diffraction grating is expressed by the following formula.

[0003]

[Formula 1]

$$\theta_1 = \sin^{-1}\left(\sin\theta_0 + \frac{m\lambda}{n_0\Lambda}\right) \qquad \cdots (1)$$

Here n_0 is the refractive index of the material surrounding the diffraction grating element.

[0004]

In this way, a diffraction grating element of this kind can be used as an optical demultiplexer for splitting incident light

and emitting it separately. Moreover, if the light is directed in the opposite direction to that described above, then this diffraction grating element can be used as an optical multiplexer for combining incident light and emitting same. Moreover, by incorporating a diffraction grating element into another optical element, for example, it is possible to constitute a differential amplifier which amplifies the group delay time of the light, according to the wavelength thereof. Consequently, diffraction grating elements are important optical devices in WDM (Wavelength Division Multiplexing) optical communications systems, which transmit signal light of multiple wavelengths by multiplexing signals.

[0005]

Furthermore, in a diffraction grating element of this kind, the greater the absolute value of the angular dispersion D_g (the wavelength dependence of the diffraction angle θ_1), then the more desirable it is in terms of the capacity to perform light multiplexing or demultiplexing readily. Here, the angular dispersion D_g is expressed by the following Formula.

[0006]

[Formula 2]

$$D_g = \frac{\partial \theta_1}{\partial \lambda} = \frac{m}{n_0 \Lambda \cos\theta_1} \qquad \cdots (2)$$

[0007]

[Non-Patent Document 1]

Kashiko Kodate "Development of Diffractive Optics and

Future Challenges", Bulletin of the Japan Women's University, Department of Science, Vol. 10, pp. 7-24, (2002)

[0008]

[Problems that the Invention is to Solve]

However, even if the wavelength of the light input to a diffraction grating element, and the incident angle thereof, are uniform, the diffraction angle will still vary depending on the temperature. When such an element is used in a WDM optical communications system, if the diffraction angle of the diffraction grating element varies, then as a result of this variation, the loss of the signal light will increase, or alternatively, the waveform of the signal light will be degraded, and a communications error may occur. In order to suppress communications errors of this kind, conventionally, it has been necessary to provide an active temperature control mechanism for controlling the temperature of the diffraction grating element to a uniform temperature. However, providing a temperature control mechanism causes an increase in system costs, and further increase in system costs is also produced by the necessity of supplying electrical power to this temperature control mechanism.

[0009]

As can be seen from the formula (2) above, it can be considered that in order to increase the absolute value of the angular dispersion, the order of diffraction, m, or the diffraction angle, θ_1, should be increased, and furthermore, the

grating period Λ should be reduced. However, in the former case, the diffraction efficiency declines, and in the latter case, the diffraction grating becomes more difficult to process, and hence there have been limits on the amount to which the absolute value of the angular dispersion can be increased. More particularly, in a conventional diffraction grating element, it has not been possible to achieve both reduction of the temperature dependence of the diffraction angle, and increase in the absolute value of the angular dispersion.

[0010]

The present invention was devised in order to resolve the aforementioned problems, an object thereof being to provide an optical component which allows the absolute value of the angular dispersion to be increased, whilst also allowing the temperature dependence of the diffraction angle to be reduced.

[0011]

[Means for Solving the Problems]

The optical component according to the present invention comprises: a transmissive type diffraction grating element wherein a diffraction grating is formed in one face of a flat plate, or in the inside of the flat plate in parallel with the face, and a prism wherein light diffracted by the diffraction grating element is input to a first surface and output from a second surface; and is characterized in that the prism is made from a material having a refractive index n_1, and the diffraction grating element and the prism are disposed in a medium having

a refractive index n_0; and if light of wavelength λ is incident on the diffraction grating element at an incident angle of θ_0, then taking the incident angle of the light incident on the first surface of the prism, from the diffraction grating element, to be θ_2, taking the emission angle of the light emitted from the second surface of the prism to be θ_5, taking the temperature coefficient of the diffraction angle in the diffraction grating element to be F_g, taking the temperature coefficient of the emission angle θ_5 of the light emitted from the second surface of the prism, assuming that the incident angle θ_2 of the light incident on the first surface of the prism is uniform regardless of the temperature, to be F_p, and taking the magnification rate of the angular dispersion caused by the prism to be M_p, there exist a wavelength λ and an incident angle θ_0 which satisfy the relationship "$n_1 > n_0$ and $|\theta_5| > |\theta_2|$" or "$n_1 < n_0$ and $|\theta_5| < |\theta_2|$", whilst also satisfying the relationship "$-2M_pF_g < F_p < 0$" or "$-2M_pF_g > F_p > 0$".

[0012]

It is preferable that the aforementioned wavelength λ is within the operational waveband of the optical component. For example, when the optical component is used for optical communications, then the wavelength λ is desirably contained within the waveband 1.26 μm to 1.675 μm, and in particular, desirably, it is contained within the C band (wavelength 1.53 to 1.565 μm) or within the L band (wavelength 1.565 to 1.625 μm). Moreover, preferably, the aforementioned relationships are

satisfied within the ambient temperature range in which the optical component is used. For example, desirably, if the optical component is used in optical communications, then the aforementioned relationships are satisfied within the temperature range −20°C to +80°C.

[0013]

In the optical component according to the present invention, the relationship "$F_p = -M_pF_g$" is preferably satisfied at any temperature contained in the temperature range of −20°C to +80°C, and in this case, the temperature coefficient of the emission angle θ_5 may be zero at any temperature contained in the aforementioned temperature range.

[0014]

In the optical component according to the present invention, taking the temperature coefficient of the emission angle θ_5 of the light emitted from the second surface of the prism to be F_t, and taking the angular dispersion of the emission angle θ_5 to be D_t, desirably, the absolute value of the ratio (F_t/D_t) is less than 0.4 pm/°C at any temperature contained in the temperature range of −20°C to +80°C, and in this case, the component is suitable for use in optical communications wherein the optical frequency spacing of the signal light is 100 GHz. Moreover, even more desirably, the absolute value of the ratio (F_t/D_t) is less than 0.2 pm/°C, and in this case, the component is suitable for use in optical communications wherein the optical frequency spacing of the signal light is 50 GHz.

[0015]

In the optical component according to the present invention, taking the angular dispersion of the diffraction grating element to be D_g, taking the temperature coefficient of the angular dispersion D_g to be G_g, and taking the temperature coefficient of the magnification rate M_p of the angular dispersion caused by the prism to be H_t, then, desirably, the relationship "$-2M_pG_g < H_tD_g < 0$" or "$-2M_pG_g > H_tD_g > 0$" is satisfied, and in this case, the temperature dependence of the angular dispersion D_t of the emission angle θ_5 can be reduced. Moreover, desirably, the relationship "$-M_pG_g = H_tD_g$" is satisfied at any temperature contained in the temperature range of −20°C to +80°C, and in this case, the temperature coefficient of the angular dispersion D_t can be made zero at any temperature within the aforementioned temperature range.

[0016]

In the optical component according to the present invention, taking the grating period of the diffraction grating to be Λ, then, desirably, the temperature coefficient of the product $(n_0\Lambda)$ has a negative value, and the temperature coefficient of the ratio (n_1/n_0) has a negative value. Moreover, in the optical component according to the present invention, desirably, the prism is made from a semiconductor, and desirably, this semiconductor is silicon. This is advantageous in terms of increasing the absolute value of the angular dispersion D_t of the emission angle θ_5, whilst also reducing the temperature

dependence of the emission angle θ_5, and furthermore, it is also advantageous in terms of reducing the temperature dependence of the angular dispersion D_t.

[0017]

The optical device according to the present invention is characterized in comprising the optical component according to the present invention as described above, wherein light is multiplexed or demultiplexed by the optical component. Desirably, the optical component is hermetically sealed inside an enclosure. The optical communications system according to the present invention is characterized in comprising the optical device according to the present invention described above, wherein signal light is transmitted, and the signal light is multiplexed or demultiplexed by the optical device. Since this optical device comprises an optical component having a large angular dispersion and low temperature dependence, it can be made compact in size, and furthermore, it becomes unnecessary to provide a temperature control mechanism, or alternatively, the temperature control mechanism can be simplified.

[0018]

[Embodiments of the Invention]

In the following, embodiments of the present invention are described in detail with reference to the accompanying drawings. In the description of the drawings, elements which are the same are labeled with the same reference numerals, and repeated description thereof is omitted. Moreover, in order to simplify

the description, an xyz-coordinates system is depicted on each of the drawings. Moreover, in the following, each wavelength dependence of the refractive indices n_0 and n_1 is ignored because it sufficiently smaller than the angular dispersion of the diffraction grating.

[0019]

Firstly, the embodiment of an optical component relating to the present invention shall be described. Fig. 1 is an illustrative diagram of an optical component 1 relating to the present embodiment. The optical component 1 shown in this diagram comprises a diffraction grating element 10, a prism 20, and a medium of refractive index n_0 which surrounds these elements. The diffraction grating element 10 comprises a diffraction grating of grating period Λ formed on one face (the upper face) of a transparent flat plate having two parallel faces in the xy plane. The respective bars or grooves formed in periodic fashion in the diffraction grating extend in a direction parallel to the x-axis. The prism 20 is made from a transparent material of refractive index n_1, and it has a first surface 21 and a second surface 22, which are not mutually parallel. The first surface 21 and the second surface 22 are respectively parallel to the x-axis.

[0020]

In an optical component 1 of this kind, the angle of inclination of the first surface 21 with respect to the xy plane is represented by ϕ_0 and the angle of inclination of the second

surface 22 with respect to the first surface 21 is represented by ϕ_1. In other words, the second surface 22 is inclined at an angle of $\phi_1 + \phi_2$ with respect to the xy plane. Moreover, the wavelength of the light input to the diffraction grating element 10 is represented by λ, the incident angle of the light input to the diffraction grating element 10 is represented by θ_0, the emission angle of the mth-order diffracted light emitted from the diffraction grating element 10 is represented by θ_1, the incident angle of the light input to the first surface 21 of the prism 20 is represented by θ_2, the angle of refraction of the light refracted at the first surface 21 of the prism 20 is represented by θ_3, the incident angle of the light input to the second surface 22 from the interior of the prism 20 is represented by θ_4, and the emission angle of the light emitted from the second surface 22 of the prism 20 is represented by θ_5. The angles ϕ_0, ϕ_1, θ_0 to θ_5, and the diffraction order m, are respectively positive in the direction illustrated in the diagrams.

[0021]

The thermal coefficient F_g of the diffraction angle θ_1 of the diffraction grating element 10, and the thermal coefficient G_g of the angular dispersion D_g (see the formula (2) above) are respectively expressed by the following formulas.

[0022]

[Formula 3]

$$F_g = \frac{\partial \theta_1}{\partial T} = -\frac{\lambda D_g}{n_0 \Lambda}\frac{d}{dT}(n_0 \Lambda) \qquad \cdots (3)$$

[Formula 4]

$$G_g = \frac{\partial D_g}{\partial T} = \left(\frac{1}{\lambda} + D_g \tan\theta_1\right) F_g \qquad \cdots (4)$$

Here, T is the temperature variable.

[0023]

Moreover, the following formulas can be established between the angles ϕ_0, ϕ_1, and θ_0 to θ_5 :

[0024]

[Formula 5]

$$\sin\theta_1 = \sin\theta_0 + \frac{m\lambda}{n_0\Lambda} \qquad \cdots (5a)$$

$$\theta_2 = \theta_1 + \phi_0 \qquad \cdots (5b)$$

$$n_1 \sin\theta_3 = n_0 \sin\theta_2 \qquad \cdots (5c)$$

$$\theta_4 = \theta_3 + \phi_1 \qquad \cdots (5d)$$

$$n_0 \sin\theta_5 = n_1 \sin\theta_4 \qquad \cdots (5e)$$

[0025]

The angular dispersion D_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is expressed by the following formula.

[0026]

[Formula 6]

$$D_t = \frac{\partial \theta_5}{\partial \lambda} = M_p D_g \qquad \cdots (6)$$

Here, M_p is the ratio between the angular dispersion D_t of the emission angle θ_5, and the angular dispersion D_g of the emission angle θ_1, in other words, the rate of magnification of the angular dispersion caused by the prism 20, and M_p is expressed by the following formula.

[0027]

[Formula 7]

$$M_p = \frac{\cos\theta_2 \cos\theta_4}{\cos\theta_3 \cos\theta_5} \quad \cdots (7)$$

[0028]

If the absolute value of the magnification rate M_p of the angular dispersion caused by the prism 20 is greater than 1, then this means that the angular dispersion D_t of the emission angle θ_5 of the light emitted from the prism 20 is greater than the angular dispersion D_g of the emission angle θ_1 of the light emitted from the diffraction grating element 10. The conditions for achieving this are expressed by the following formula.

[0029]

[Formula 8]

(Numerator in Formula (7))^2 – (Denominator in Formula (7))^2

$$= \frac{1}{n_1^2}(n_1^2 - n_0^2)(\sin^2\theta_5 - \sin^2\theta_2) > 0 \quad \cdots (8)$$

Furthermore, from Formula (8), the following formula can be derived.

[0030]

[Formula 9]

$n_1 > n_0$ AND $|\theta_5| > |\theta_2|$ ···(9a)

OR

$n_1 < n_0$ AND $|\theta_5| < |\theta_2|$ ···(9b)

[0031]

As shown by Formula (9), if the refractive index n_1 of the prism 20 is greater than the refractive index n_0 of the surrounding medium, then the refractive index n_1 of the prism 20, the angle of inclination ϕ_0 of the first surface 21, and the angle of inclination ϕ_1 of the second surface 11 should be designed appropriately in such a manner that the absolute value of the emission angle $|\theta_5|$ is greater than the absolute value of the incident angle $|\theta_2|$. On the other hand, if the refractive index n_1 of the prism 20 is less than the refractive index n_0 of the surrounding medium, then the refractive index n_1 of the prism 20, the angle of inclination ϕ_0 of the first surface 21, and the angle of inclination ϕ_1 of the second surface 22 should be designed appropriately in such a manner that the absolute value of the emission angle $|\theta_5|$ is less than the absolute value of the incident angle $|\theta_2|$. By this means, the absolute value of the magnification rate M_p of the angular dispersion caused by the prism 20 will be greater than 1, and hence the angular dispersion D_t of the optical component 1 as a whole will be greater than the angular dispersion D_g created by the diffraction grating element 10 alone.

[0032]

Next, the decrease in temperature dependence of the

emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 will be described. In this optical component 1, the temperature coefficient F_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is expressed by the following formula.

[0033]

[Formula 10]

$$F_t = \frac{\partial \theta_5}{\partial T} = M_p F_g + F_p \qquad \cdots (10)$$

[0034]

Here, F_p is the temperature coefficient of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20, if it is assumed that the incident angle θ_2 of the light incident on the first surface 21 of the prism 20 is constant, regardless of the temperature. This temperature coefficient F_p is expressed by the formula

[0035]

[Formula 11]

$$F_p = M_p \frac{\sin \phi_1}{\cos \theta_2 \cos \theta_4} \frac{d}{dT} \left(\frac{n_1}{n_0} \right) \qquad \cdots (11)$$

[0036]

Therefore, from formula (10) above, it can be seen that if the relationship

[0037]

[Formula 12]

$$-2M_pF_g < F_p < 0 \quad \cdots (12a)$$

OR

$$-2M_pF_g > F_p > 0 \quad \cdots (12b)$$

is satisfied, then the absolute value of the temperature coefficient F_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 in this optical component 1 will be smaller than the absolute value of the product of the temperature coefficient F_g of the emission angle θ_1 of the light emitted from the diffraction grating element 10, multiplied by the magnification rate M_p of the angular dispersion caused by the prism 20.

[0038]

Furthermore, desirably, the relationship will be satisfied, when the temperature is at any temperature between −20°C and +80°C.

[0039]

[Formula 13]

$$F_p = -M_pF_g \quad \cdots (13)$$

In this case, the absolute value of the temperature coefficient F_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 in the optical component 1 becomes zero at the temperature at which formula (13) is satisfied, and furthermore, it assumes a small value within the temperature range indicated above.

[0040]

If an optical component 1 of this kind is used in WDM (Wavelength Division Multiplexing)-based optical communications, then, desirably, the absolute value of the ratio (F_t/D_t) represented by the following formula.

[0041]

[Formula 14]

$$\left|\frac{F_t}{D_t}\right| = \left|\frac{F_g}{D_g} + \frac{F_p}{M_p D_g}\right| \qquad \cdots (14)$$

will be small at any temperature in the temperature range of −20°C to +80°C. Here, the ratio (F_t/D_t) represents the temperature dependence of the wavelength of the light arriving at a certain observation point after emission from the prism 20.

[0042]

For example, if the optical frequency spacing of the signal light is 100 GHz, then desirably, at any temperature in the temperature range between −20°C and +80°C, the absolute value of the ratio (F_t/D_t) is less than 0.4 pm/°C (= 40 pm/100°C). Moreover, if the optical frequency spacing of the signal light is 50 GHz, then desirably, at any temperature in the temperature range between −20°C and +80°C, the absolute value of the ratio (F_t/D_t) is less than 0.2 pm/°C (= 20 pm/100°C).

[0043]

Next, the decrease in the temperature dependence of the angular dispersion D_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 will be

explained. Even if the temperature dependence of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is decreased as described above, then if the temperature dependence of the angular dispersion D_t of this emission angle θ_5 is large, and if there is a variation in temperature, although the emission angle θ_5 for any particular wavelength will be approximately the same, the emission angle θ_5 for other wavelengths will change significantly. Therefore, it is desirable that the temperature dependence of the angular dispersion D_t is also small.

[0044]

The temperature coefficient G_t of the angular dispersion D_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is represented by the following formula.

[0045]

[Formula 15]

$$G_t = \frac{\partial D_t}{\partial T} = M_p G_g + H_t D_g \qquad \cdots (15a)$$

$$H_t = A_p + B_p F_t = \frac{\partial M_p}{\partial T} \qquad \cdots (15b)$$

Here, H_t is the temperature coefficient of the magnification rate M_p of the angular dispersion caused by the prism 20. Moreover, the parameters A_p and B_p in the formula for the temperature coefficient H_t are respectively expressed by the following formula.

[0046]

[Formula 16]

$$A_p = F_p\left(\tan\theta_2 + \frac{n_0\cos\theta_2}{n_1\cos\theta_3}\tan\theta_4\right) \quad \cdots (16a)$$

$$B_p = M_p\tan\theta_5 - \tan\theta_2 + (\tan\theta_3 - \tan\theta_4)\frac{n_0\cos\theta_2}{n_1\cos\theta_3} \quad \cdots (16b)$$

[0047]

Since the temperature coefficient F_t is already a sufficiently small value, in Formula (15) above, the item containing the temperature coefficient F_t as a factor can be ignored. Furthermore, if the relationship

[0048]

[Formula 17]

$$-2M_pG_g < H_tD_g < 0 \quad \cdots (17a)$$

OR

$$-2M_pG_g > H_tD_g > 0 \quad \cdots (17b)$$

is satisfied, then the absolute value of the temperature coefficient G_t of the angular dispersion D_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 in this optical component 1 will be less than the absolute value of the product of the temperature coefficient G_g of the angular dispersion D_g of the emission angle θ_1 of the light emitted from the diffraction grating element 10, multiplied by the magnification rate M_p of the angular dispersion caused by the prism 20.

[0049]

Furthermore, desirably, the relationship

[0050]

[Formula 18]

$$-M_pG_g = H_tD_g \qquad \cdots (18)$$

should be satisfied at any temperature in the temperature range of −20°C to +80°C. In this case, the absolute value of the temperature coefficient G_t of the angular dispersion D_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 in the optical component 1 will become zero at the temperature where this formula (18) is satisfied, and it will have a small value within the temperature range indicated above.

[0051]

If an optical component of this kind is used in WDM-based optical communications, then desirably, the absolute value of the ratio (G_t/D_t) is small at any temperature in the temperature range of −20°C to +80°C. Here, the ratio (G_t/D_t) represents the temperature dependence of the wavelength band of the light arriving at a particular observation point after emission from the prism 20.

[0052]

For example, when the waveband of the signal light is C-band (1.53 µm to 1.565 µm), then if the optical frequency spacing of the signal light is 100 GHz, then desirably, the absolute value of the ratio (G_t/D_t) is 11.4 pm/°C/µm (= 0.4 pm/°C/(1.565 µm to 1.53 µm)), or less, and if the optical frequency spacing of the signal light is 50 GHz, then desirably, the absolute value of

the ratio (G_t/D_t) is 5.7 pm/°C/μm (= 0.2 pm/°C/(1.565 μm to 1.53 μm)), or less.

[0053]

When the waveband of the signal light is L-band (1.565 μm to 1.625 μm), then if the optical frequency spacing of the signal light is 100 GHz, then desirably, the absolute value of the ratio (G_t/D_t) is 6.7 pm/°C/μm or less, and if the optical frequency spacing of the signal light is 50 GHz, then desirably, the absolute value of the ratio (G_t/D_t) is 3.3 pm/°C/μm or less.

[0054]

Furthermore, when the waveband of the signal light contains both C-band and L-band, then if the optical frequency spacing of the signal light is 100 GHz, then desirably, the absolute value of the ratio (G_t/D_t) is 4.2 pm/°C/μm or less, and if the optical frequency spacing of the signal light is 50 GHz, then desirably, the absolute value of the ratio (G_t/D_t) is 2.1 pm/°C/μm or less.

[0055]

In this way, it is possible to increase the absolute value of the angular dispersion D_t of the emission angle θ_5 in the optical component 1, and it is also possible to reduce the absolute value of the temperature coefficient F_t of the emission angle θ_5, and to reduce the absolute value of the temperature coefficient G_t of the angular dispersion D_t. The refractive index n_1 of the prism 20, the temperature coefficient of the refractive index n_1, the angle of inclination ϕ_0 of the first

surface 21, and the angle of inclination ϕ_1 of the second surface 22, should be designed appropriately in such a manner that the various formulas stated above are satisfied.

[0056]

If there is backlight reflected to the diffraction grating element 10 from the prism 20, then the diffraction efficiency will be degraded by interference of the light. Therefore, desirably, the prism 20 or the diffraction grating element 10 are processed in order to reduce reflections. For example, desirably, reflection of light of the used diffraction order is reduced by means of an anti-reflection film provided on the surface of the prism 20, and the width of the prism 20 is adjusted and the light is shielded by slits, and the like, in such a manner that light of other orders does not enter into the prism 20. Furthermore, desirably, the position and angle of the reflected light is offset by adjusting the angle and position of the prism 20, in such a manner that no interference of the light occurs.

[0057]

Next, concrete Embodiments 1 to 4 of an optical component 1 relating to the present embodiment shall be described. Of these, in each of Embodiments 1 to 3, the diffraction grating element 10 is made from silica glass, the grating period Λ is 1.012 μm, the thermal expansion coefficient of the grating period Λ is 5×10^{-7}/°C, the surrounding medium is atmospheric air ($n_0 = 1$), and the thermal coefficient of the refractive index n_0 of the surrounding medium at a temperature of 30°C

$(1/n_0 \cdot dn_0/dT)$ is -8.6×10^{-7}/°C. Moreover, light having a central wavelength of 1.55 μm is input to the diffraction grating element 10, and the incident angle thereof θ_0 is 50 degrees. In this case, the diffraction angle θ_1 of the minus-first-order light is −50.0°, the angular dispersion D_g in the diffraction grating element 10 is −88.1 deg./μm, the temperature coefficient F_g of the diffraction angle θ_1 is -4.90×10^{-5} deg./°C, the temperature coefficient G_g of the angular dispersion D_g is -1.21×10^{-4} deg./μm/°C, the amount of wavelength shift (F_g/D_g) is 0.556 pm/°C, and the amount of change in the waveband (G_g/D_g) is 1.38 pm/°C/μm.

[0058]

In Embodiment 1, the prism 20 is made of S-PHM52 glass manufactured by Ohara Ltd. This glass has a refractive index n_1 of 1.60, and a temperature coefficient of the refractive index n_1 $(1/n_1 \cdot dn_1/dT)$ of -3.42×10^{-6}/°C. The respective parameters required in order to satisfy Formula (9), Formula (13) and Formula (18) above were determined to be as follows. The angle of inclination ϕ_0 of the first surface 21 is −2.37°, the angle of inclination ϕ_1 of the second surface 22 of the prism 20 is −5.94°, the incident angle θ_2 of the light incident on the first surface 21 of the prism 20 is −52.4°, and the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is −68.7°. In the optical component 1 as a whole, the angular dispersion D_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is −139 deg./μm, the temperature coefficient F_t of the emission angle θ_5 is

approximately 0 deg./°C, and the temperature coefficient G_t of the angular dispersion D_t is approximately 0 deg./μm/°C. The wavelength shift (F_t/D_t) is approximately 0 pm/°C, and the change in the waveband (G_t/D_t) is approximately 0 pm/°C/μm. Moreover, the magnification rate M_p of the angular dispersion caused by the prism 20 is 1.57. In this way, in Embodiment 1, it is possible to increase the absolute value of the angular dispersion D_t, whilst also being able to reduce both the temperature coefficient F_t of the emission angle θ_5 and the temperature coefficient G_t of the angular dispersion D_t virtually to zero, thus removing the need for a temperature control mechanism, or making it possible to simplify same.

[0059]

Embodiment 2 is similar to Embodiment 1 in view of the fact that the prism 20 is made from S-PHM52 glass manufactured by Ohara Ltd., but here the angle of inclination ϕ_0 of the first surface 21 of the prism 20 is taken to be 0°. The respective parameters satisfying Formula (9) and Formula (13) above were determined to be as follows. The angle of inclination ϕ_1 of the second surface 22 of the prism 20 is −6.31°, the incident angle θ_2 of the light incident on the first surface 21 of the prism 20 is −50.0°, and the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is −66.3°. In the optical component 1 as a whole, the angular dispersion D_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is −132 deg./μm, the temperature

coefficient F_t of the emission angle θ_5 is approximately 0 deg./°C, and the temperature coefficient G_t of the angular dispersion D_t is approximately -1.13×10^{-5} deg./μm/°C. The wavelength shift (F_t/D_t) is approximately 0 pm/°C, and the change in the waveband (G_t/D_t) is approximately 0.09 pm/°C/μm. Moreover, the magnification rate M_p of the angular dispersion caused by the prism 20 is 1.50. In this way, in Embodiment 2, it is possible to increase the absolute value of the angular dispersion D_t, whilst being able to reduce the temperature coefficient F_t of the emission angle θ_5 virtually to zero, and to reduce the temperature coefficient G_t of the angular dispersion D_t to a very small value, thus removing the need for a temperature control mechanism, or making it possible to simplify same.

[0060]

In Embodiment 3, the refractive index n_1 and the temperature coefficient of the refractive index are optimized by adjusting the composition of the glass forming the material of the prism 20. For example, the refractive index n_1 of the glass forming the material of the prism 20 is set to be 1.44 and the temperature coefficient of this refractive index is set to be -3.58×10^{-6}/°C. The respective parameters for satisfying Formula (9), Formula (13) and Formula (18) were determined to be as follows. The angle of inclination ϕ_0 of the first surface 21 of the prism 20 is 0°, the angle of inclination ϕ_1 of the second surface 22 of the prism 20 is -6.31°, the incident angle θ_2 of the light incident on the first surface 21 of the prism

20 is −50.0°, and the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is −63.5°. In the optical component 1 as a whole, the angular dispersion D_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is −118 deg./µm, the temperature coefficient F_t of the emission angle θ_5 is approximately 0 deg./°C, and the temperature coefficient G_t of the angular dispersion D_t is approximately 0 deg./µm/°C. The wavelength shift (F_t/D_t) is approximately 0 pm/°C, and the change in the waveband (G_t/D_t) is approximately 0 pm/°C/µm. Moreover, the magnification rate M_p of the angular dispersion caused by the prism 20 is 1.33. In this way, in Embodiment 3, it is possible to increase the absolute value of the angular dispersion D_t, whilst being able to reduce both the temperature coefficient F_t of the emission angle θ_5 and the temperature coefficient G_t of the angular dispersion D_t virtually to zero, thus removing the need for a temperature control mechanism, or making it possible to simplify same.

[0061]

In the Embodiments 2 and 3 described above, since the angle of inclination ϕ_0 of the first surface 21 of the prism 20 is 0°, and the first surface 21 of the prism 20 and the lower face of the diffraction grating element 10 are mutually parallel, then as shown in Fig. 2, desirably, the first surface 21 of the prism 20 and the lower face of the diffraction grating element 10 are bonded together, and by adopting this composition, the

optical component 1 becomes easy to manufacture and handle. Furthermore, if the diffraction grating element 10 and the prism 20 are bonded in this way, then desirably, there should be zero difference (or very small difference) between the respective linear thermal expansivity values of the diffraction grating element 10 and the prism 20, and by adopting a composition of this kind, it is possible to achieve performance characteristics that match the aforementioned design.

[0062]

Furthermore, in the diffraction grating element 10 according to Embodiments 1 to 3 described above, the temperature coefficient of the product ($n_0\Lambda$) expressed by the relationship

[0063]

[Formula 19]

$$\frac{1}{n_0\Lambda}\frac{d}{dT}(n_0\Lambda)=\frac{1}{n_0}\frac{dn_0}{dT}+\frac{1}{\Lambda}\frac{d\Lambda}{dT} \quad \cdots (19)$$

is -3.6×10^{-7}/°C, which is distinctive in that it is a negative value. Moreover, in order to counteract this temperature dependence, the prism 20 is also characterized in that it has a negative value for the temperature coefficient of the ratio (n_1/n_0) as expressed by the formula

[0064]

[Formula 20]

$$\frac{1}{n_1/n_0}\frac{d}{dT}\left(\frac{n_1}{n_0}\right)=\frac{1}{n_1}\frac{dn_1}{dT}-\frac{1}{n_0}\frac{dn_0}{dT} \quad \cdots (20)$$

[0065]

In Embodiment 4 described below, the temperature coefficient of the product ($n_0\Lambda$) is positive. The greater the ratio between the refractive index n_0 of the surrounding medium and the refractive index of the material of the diffraction grating element 10, the greater the diffraction efficiency, even if the height of the bars and grooves of the diffraction grating is low, and therefore the easier it is to manufacture the diffraction grating. However, glass of high refractive index of this kind generally has a coefficient of linear expansion of 5×10^{-6}/°C or above, and therefore the temperature coefficient of the product ($n_0\Lambda$) is positive.

[0066]

In Embodiment 4, the grating period Λ is 1.012 μm, the coefficient of linear expansion of the grating period Λ is 6.6×10^{-6}/°C, the surrounding medium is atmospheric air ($n_0 = 1$), and the temperature coefficient of the refractive index n_0 of the surrounding medium at a temperature of 30°C is -8.6×10^{-7}/°C. Furthermore, light of central wavelength 1.55 μm is input to the diffraction grating element 10, and the incident angle θ_0 in this case is 50°. Here, in the diffraction grating element 10 alone, the diffraction angle of the minus-first-order light θ_1 is -50.0°, the angular dispersion D_g of the diffraction grating element 10 is -88.1 deg./μm, the temperature coefficient F_g of the diffraction angle θ_1 is 7.84×10^{-4} deg./°C, the temperature coefficient G_g of the angular dispersion D_g is 1.94×10^{-3} deg./μm/°C, the wavelength shift (F_g/D_g) is -8.90 pm/°C, and the

amount of change in the waveband (G_g/D_g) is -22.1 pm/°C/μm.

[0067]

In Embodiment 4, the absolute value of the temperature coefficient of the product ($n_0\Lambda$) is at least one order of ten greater than in the case of silica glass, and therefore, the absolute value of the temperature coefficient of the refractive index n_1 of the prism 20 must also be at least one order of ten greater than in the case of silica glass. Therefore, desirably, the material of the prism 20 is a semiconductor material, and in particular, desirably, it is silicon. Silicon has a refractive index of 3.48 and the thermal coefficient of this refractive index is 45.7×10^{-6}/°C. The respective parameters required in order to satisfy Formula (9), Formula (13) and Formula (18) above, if the prism 20 is made from silicon, were determined to be as follows.

[0068]

The angle of inclination ϕ_0 of the first surface 21 of the prism 20 is -7.41°, the angle of inclination ϕ_1 of the second surface 22 of the prism 20 is -2.50°, the incident angle θ_2 of the light incident on the first surface 21 of the prism 20 is -57.4°, and the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is -81.5°. In the optical component 1 as a whole, the angular dispersion D_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is -319 deg./μm, the temperature coefficient F_t of the emission angle θ_5 is approximately 0 deg./°C, and the

temperature coefficient G_t of the angular dispersion D_t is approximately 0 deg./μm/°C. The wavelength shift (F_t/D_t) is approximately 0 pm/°C, and the change in the waveband (G_t/D_t) is approximately 0 pm/°C/μm. Moreover, the magnification rate M_p of the angular dispersion caused by the prism 20 is 3.62.

[0069]

In this way, in Embodiment 4 as well, it is possible to increase the absolute value of the angular dispersion D_t, whilst being able to reduce both the temperature coefficient F_t of the emission angle θ_5 and the temperature coefficient G_t of the angular dispersion D_t virtually to zero, thus removing the need for a temperature control mechanism, or making it possible to simplify same. In particular, in Embodiment 4, by using a semiconductor material having a high absolute value for the temperature coefficient of the refractive index n_1 as the material for the prism 20, it is possible to use optical glass having a large coefficient of linear expansion as the material for the diffraction grating element 10. Since optical glass having a large coefficient of linear expansion has a high refractive index, by using optical glass of this kind, it is possible readily to manufacture a diffraction grating element 10 having high diffraction efficiency, even if the bars and grooves of the diffraction grating are low in height.

[0070]

Moreover, it is also possible to use another semiconductor as the material for the prism 20, and in addition to Si (which

has a thermal coefficient of refractive index = 45.7 × 10^{-6}/°C), it would also be appropriate to use, for example, ZnS (thermal coefficient of refractive index = 19.4 × 10^{-6}/°C), InP (thermal coefficient of refractive index = 27 × 10^{-6}/°C), GaAs (thermal coefficient of refractive index = 59 × 10^{-6}/°C), ZnSe (thermal coefficient of refractive index = 52 × 10^{-6}/°C), InGaAsP (thermal coefficient of refractive index = 65 × 10^{-6}/°C), or the like. The thermal coefficients of the refractive index of the various semiconductors stated above are values for the wavelengths used in optical communications, and in all cases, they have a larger absolute value than standard optical glass.

[0071]

In the foregoing, an optical component 1 was described which operates as an optical demultiplexer, but if the light were to travel in the opposite direction to that described above, then this optical component 1 could operate as an optical multiplexer.

[0072]

Moreover, as shown in Fig. 3, if the optical component 1 is used together with reflective mirrors 31 to 34 which reflect light emitted from the second surface 22 of the prism 20, then the optical device 2 comprising the optical component 1 and the reflective mirrors 31 to 34 first splits the incident light by means of the optical component 1, and then reflects the light of various wavelengths thus split, by means of the reflecting mirrors 31 to 34, and combines the light thus reflected, by means

of the optical component 1. In this case, by establishing a suitable optical path length for each wavelength from splitting until coupling (in other words, by setting the reflecting mirrors 31 to 34 in suitable positions), the optical device 2 can be used as a dispersion adjuster for adjusting the group delay time of light of respective wavelengths. This optical device 2 can also be used as an optical circulator (see Fig. 6).

[0073] Furthermore, as shown in Fig. 4, the optical component 1 is used together with photoreceptor elements 41 to 44 which detect the optical power emitted from the second surface 22 of the prism 20, then an optical device 3 containing this optical component 1 and the photoreceptor elements 41 to 44 can be used as a spectral detector for detecting the optical power at respective wavelengths.

[0074]

Furthermore, as illustrated in Fig. 5, in an optical device 4 including two optical components 1a, 1b of the same composition as the optical component 1 described above, and optical attenuators 51 to 54, incident light is split by the optical component 1a (optical demultiplexer), whereupon a prescribed loss is applied to the light of respective wavelengths split in this manner, by means of the optical attenuators 51 to 54, and then the light of respective wavelengths is combined by means of the optical component 1b (optical multiplexer). This optical device 4 may be used as an optical filter, and it may also be used as a gain equalizer for equalizing the gain of an optical

amplifier. In the composition illustrated in Fig. 3, if optical attenuators are inserted between the optical component 1 and the reflecting mirrors 31 to 34, then it is also possible to achieve an optical filter.

[0075]

As described above, an optical device including the optical component 1 can be used suitably in a WDM optical communications system, as an optical demultiplexer, optical multiplexer, dispersion adjuster, spectral detection device, and optical filter, and the like. Furthermore, optical devices of these kinds may also include semiconductor components, such as a laser diode, photodiode, MEMS (Micro Electro Mechanical System), or the like. Generally, a semiconductor component is sealed hermetically in order to prevent degradation caused by the effects of moisture, water vapour, or the like. Furthermore, even in an optical device which does not contain semiconductor components, by hermetically sealing the device, it is possible to maintain good characteristics, by suppressing the adherence of foreign matter to the diffraction grating element 10 or prism 20. Below, specific examples of decrease in the temperature dependence of the diffraction characteristics achieved by hermetic sealing are described.

[0076]

The refractive index n of a gas is generally represented by the following formula.

[0077]

[Formula 21]

$$n = 1 + \Delta n \qquad \cdots (21)$$

Here, Δn indicates the difference with respect to the refractive index in a vacuum, which varies depending on the gas concerned, and the respective values for He, Ne, Ar and N_2 at a temperature of 0°C and pressure of 1 atmosphere are as follows:

[0078]

[Formula 22]

$$\text{He} \qquad \Delta n = 0.35 \times 10^{-4} \qquad \cdots (22a)$$

$$\text{Ne} \qquad \Delta n = 0.67 \times 10^{-4} \qquad \cdots (22b)$$

$$\text{Ar} \qquad \Delta n = 2.84 \times 10^{-4} \qquad \cdots (22c)$$

$$\text{N}_2 \qquad \Delta n = 2.97 \times 10^{-4} \qquad \cdots (22d)$$

[0079]

If the temperature or pressure changes, then the value of Δn changes approximately in direct proportion to the density of the gas. The gas density when hermetically sealed is taken to be ρ_o, the gas temperature when hermetically sealed is taken to be T_o, and the coefficient of volumetric expansion of the gas is taken to be γ. In this case, the refractive index n of the gas when the temperature is T is expressed by the formula

[0080]

[Formula 23]

$$n = 1 + \Delta n \frac{\rho}{\rho_0} \qquad \cdots (23)$$

and the density ρ of the gas when the temperature is T is expressed by the following formula.

[0081]

[Formula 24]

$$\frac{\rho}{\rho_0}=1-\gamma(T-T_0) \qquad \cdots(24)$$

Therefore, the temperature coefficient β of the refractive index of the hermetically sealed gas will be represented by the following formula.

[0082]

[Formula 25]

$$\beta=\frac{1}{n}\frac{dn}{dT}\approx-\Delta n\gamma \qquad \cdots(25)$$

[0083]

If the material of the enclosure in which the optical component 1 (or semiconductor component) is accommodated and sealed is aluminium, then the coefficient of linear expansion of the enclosure is 23×10^{-6}/°C, and therefore the coefficient of volumetric expansion γ is 69×10^{-6}/°C (= $3 \times 23 \times 10^{-6}$). Therefore, the temperature coefficient β of the refractive index of the hermetically sealed gas will be -0.024×10^{-7}/°C, in the case of He gas, and -0.20×10^{-7}/°C in the case of N_2 gas.

[0084]

The absolute value of this temperature coefficient β of the refractive index of the hermetically sealed gas is at least one order of ten less than the coefficient of linear expansion (5

$\times 10^{-7}/°C$) of the silica glass. Furthermore, at atmospheric pressure, the coefficient of volumetric expansion of the gas is inversely proportional to the absolute temperature, and if the temperature is 0°C, for example, then it have a value of $3.7 \times 10^{-3}/°C$ (= 1/273), and hence the absolute value of the coefficient of volumetric expansion γ of the gas hermetically sealed in an aluminium frame will be at least two orders of ten smaller than the coefficient of volumetric expansion of the gas in atmospheric conditions.

[0085]

Therefore, if sealed hermetically by means of an enclosure made from a material having a high coefficient of linear expansion, such as aluminium, then the temperature dependence of the refractive index n_0 of the medium (generally, a gas) surrounding the diffraction grating element 10 and the prism 20, including a vacuum, will be so small that it can be ignored. Even if the component is sealed, if the material surrounding the diffraction grating element 10 and the prism 20 is one having a high coefficient of linear expansion, such as resin, then it is necessary to take account of the thermal coefficient β of the refractive index of the gas when hermetically sealed, when seeking to satisfy Formula (9) and Formula (12) above, and the like.

[0086]

Next, an embodiment of an optical component which is hermetically sealed in this manner will be described. In the

present embodiment, the diffraction grating element 10 and the prism 20 are disposed inside an enclosure made of a material having a lower coefficient of linear expansion than aluminium, and are sealed therein. The diffraction grating element 10 is made from silica glass, the grating period Λ is 1.012 μm, the coefficient of linear expansion of the grating period Λ is 5 × 10^{-7}/°C, and refractive index n_0 of the surrounding medium is 1, and the temperature coefficient of the refractive index n_0 of the surrounding medium is so small as to be negligible. Moreover, light of central wavelength 1.55 μm is introduced to the diffraction grating element 10, and the incident angle θ_o in this case is 50°. In the diffraction grating element 10 alone, the diffraction angle θ_1 of the minus-first-order light is −50.0°, the angular dispersion D_g in the diffraction grating element 10 is −88.1 deg./μm, the temperature coefficient F_g of the diffraction angle θ_1 is 6.83 × 10^{-5} deg./°C, the temperature coefficient G_g of the angular dispersion D_g is 1.69 × 10^{-4} deg./μm/°C, the amount of wavelength shift (F_g/D_g) is −0.775 pm/°C, and the amount of change in the waveband (G_g/D_g) is −1.92 pm/°C/μm.

[0087]

The prism 20 is made from silica glass. This silica glass has a refractive index n_1 of 1.45, and a temperature coefficient of the refractive index n_1 ($1/n_1 \cdot dn_1/dT$) of 6 × 10^{-6}/°C. The angle of inclination ϕ_0 of the first surface 21 of the prism 20 is 0°. The respective parameters required in order to satisfy

Formula (9) and Formula (13) above were determined to be as follows. The angle of inclination ϕ_1 of the second surface 22 of the prism 20 is −4.09°, the incident angle θ_2 of the light incident on the first surface 21 of the prism 20 is −50.0°, and the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is −58.4°. In the optical component 1 as a whole, the angular dispersion D_t of the emission angle θ_5 of the light emitted from the second surface 22 of the prism 20 is −103 deg./μm, the temperature coefficient F_t of the emission angle θ_5 is approximately 0 deg./°C, and the temperature coefficient G_t of the angular dispersion D_t is approximately 4.98×10^{-6} deg./μm/°C. The wavelength shift (F_t/D_t) is approximately 0 pm/°C, and the change in the waveband (G_t/D_t) is approximately −0.04 pm/°C/μm. Moreover, the magnification rate M_p of the angular dispersion caused by the prism 20 is 1.17. In this way, in the present embodiment, it is possible to increase the absolute value of the angular dispersion D_t, whilst also being able to reduce the temperature coefficient F_t of the emission angle θ_5 virtually to zero, and to reduce the temperature coefficient G_t of the angular dispersion D_t to a very small value, thus removing the need for a temperature control mechanism, or making it possible to simplify same.

[0088]

In this embodiment, since the diffraction grating element 10 and the prism 20 are both made from the same material, then

even if the diffraction grating element 10 and the prism 20 are bonded mutually together, it is possible to achieve performance that matches the designed characteristics, and the optical component 1 becomes easy to manufacture and handle. Moreover, the diffraction grating element 10 and the prism 20 may be formed in an integrated fashion, and a diffraction grating may be formed on one face of the prism.

[0089]

Next, an embodiment of an optical communications system relating to the present invention will be described. Fig. 6 is a compositional diagram of an optical communications system 100 relating to the present embodiment. The optical communications system 100 illustrated in this diagram comprises an optical transmitter 110, an optical repeater 120 and an optical receiver 130, an optical fibre transmission path 140 being laid between the optical transmitter 110 and the optical repeater 120, and an optical fibre transmission path 150 being laid between the optical repeater 120 and the optical receiver 130.

[0090]

The optical transmitter 110 comprises light sources 111 to 114 and an optical multiplexer 115. The light sources 111 to 114 output signal light of mutually different wavelengths. The optical multiplexer 115 combines the signal lights output by the respective light sources 111 to 114, and outputs this combined multiple-wavelength signal light to the optical fibre transmission path 140.

[0091]

The optical repeater 120 comprises an optical amplifier 121, a gain equalizer 122, an optical coupler 123, and a spectral detector 124. The optical amplifier 121 inputs signal light that reaches it after being transmitted along the optical fibre transmission path 140, and it amplified this signal light, optically, and then outputs the amplified light. The gain equalizer 122 inputs the signal light output by the optical amplifier 121 and applies losses corresponding to wavelength to the signal light, thereby equalizing the gain of the amplifier 121. The optical coupler 123 splits off a portion of the signal light output by the gain equalizer 122 and outputs same to the spectral detector 124, whilst outputting the remainder of the signal light to the optical fibre transmission path 150. The spectral detector 124 monitors the power of the signal light arriving from the optical coupler 123, for each wavelength. The respective operations of the optical amplifier 121 and the gain equalizer 122 are controlled on the basis of the monitoring results provided by the spectral detector 124.

[0092]

The optical receiver 130 comprises photoreceptors 131 to 134, an optical demultiplexer 135, an optical circulator 136, and a dispersion adjuster 137. The optical circulator 136 inputs signal light arriving at it after being transmitted along the optical fibre transmission path 150, and outputs this signal light to the dispersion adjuster 137. Moreover, the optical

circulator 136 inputs the signal light reaching it from the dispersion adjuster 137, and outputs this signal light to the optical demultiplexer 135. The optical demultiplexer 135 inputs the multiple-wavelength signal light output by the dispersion adjuster 137, and splits this signal light into separate wavelengths, the signal light of each respective wavelength being output to the photoreceptors 131 to 134. The photoreceptors 131 to 134 receive the signal light arriving from the optical demultiplexer 135.

[0093]

This optical communications system 100 operates in the following manner. In the optical transmitter 110, the signal light output by the respective light sources 111 to 114 is combined by the optical multiplexer 115, and output to the optical fibre transmission path 140. At the optical repeater 120, the multiple-wavelength signal light arriving after transmission along the optical fibre transmission path 140 is optically amplified by the optical amplifier 121, and the power at each wavelength is equalized by the gain equalizer 122, whereupon the light is output to the optical fibre transmission path 150. Furthermore, the power of the signal light at each respective wavelength output to the optical fibre transmission path 150 is monitored by the spectral detector 124, and the operation of both the optical amplifier 121 and the gain equalizer 122 is controlled on this basis of the results of this monitoring, whereby, even there is variation in the frequency

of the signal light arriving at the optical repeater 120, or the like, the power of the signal light at each wavelength output to the optical fibre transmission path 150 will be equalized. In the optical receiver 130, the multiple-wavelength signal light arriving the receiver after transmission along the optical fibre transmission path 150 is input via the optical circulator 136 to the dispersion adjuster 137, and dispersion of the light is compensated by the dispersion adjuster 137, and the light is then passed back through the optical circulator 136 and input to the optical demultiplexer 135. The multiple-wavelength signal light input to the optical demultiplexer 135 is split into respective wavelengths by the optical demultiplexer 135, and is then received by the photoreceptors 131 to 134.

[0094]

In an optical communications system 100 of this kind, the optical component 1 described above is used respectively as an optical multiplexer 115 and an optical demultiplexer 135, the optical device 4 described above is used as a gain equalizer 122, the optical device 3 described above is used as a spectral detector 124, and the optical device 2 described above is used as a dispersion adjuster 137. Therefore, since the emission angle from the optical component 1 has low temperature dependence, this optical communications system 1 does not require a temperature control mechanism, or alternatively, the temperature control mechanism thereof can be simplified. Moreover, since the absolute value of the angular dispersion of

the optical component 1 is large, the respective devices can be made more compact in size.

[0095]

[Effects of the Invention]

As described in detail above, in accordance with the present invention, it is possible to increase the absolute value of the angular dispersion of the emission angle, whilst also being able to reduce the temperature dependence of the emission angle.

[Brief Description of the Drawings]

[Fig. 1]

It is a view for explaining the optical component 1 according to the present embodiment.

[Fig. 2]

It is a view for explaining the optical component 1 according to another embodiment.

[Fig. 3]

It is a view for explaining the optical device 2 according to the present embodiment.

[Fig. 4]

It is a view for explaining the optical device 3 according to the present embodiment.

[Fig. 5]

It is a view for explaining the optical device 4 according to the present embodiment.

[Fig. 6]

It is a view showing a configuration of the optical communications system 100 according to the present embodiment.

[Description of the Reference Numerals]

1 ··· optical component; 2-4 ··· optical device; 10 ··· diffractive grating element; 20 ··· prism; and 100 ··· optical transmission system.